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Rocket-Grenade Measurements of Temperatures and Winds in the Arctic Mesosphere

The following report is based on material by W. G. Stroud, W. Nordberg, W. R. Bandeen, F. L. Bartman, and P. Titus. Stroud, Nordberg, and Bandeen were with the U. S. Army Signal Research and Development Laboratory when the experiment was conducted; they are now with the National Aeronautics and Space Administration. Bartman and Titus are at the University of Michigan. A more complete account was published in the Journal of Geophysical Research, *August 1960.*

In an effort to develop a model of atmospheric behavior in the 30 to 90 km region, rocket-grenade experiments were used during and just prior to the IGY to obtain temperature and wind measurements in three typical areas of the globe. The experiments were conducted at White Sands, New Mexico, in middle latitudes; at the arctic rocket facility at Fort Churchill, Canada; and at the equatorial Western Pacific island of Guam. This report deals with results of IGY rocket launchings at Fort Churchill during November 1956, July, August, and December 1957, and January 1958. Some comparisons are made with the White Sands data of 1950–53; results of the Guam program of November 1958 are not yet available.

In the Fort Churchill experiment, 10 Aerobee rockets carried aloft and ejected 18 or 19 high-explosive grenades each. A total of 150 measurements were thus obtained, each representing the average temperature and wind vector of an atmospheric layer about three kilometers thick (between two exploded grenades), as follows:

The position in space and the time of each explosion were determined through electronic tracking, and an array of microphones on the ground recorded the arrival of the sound waves. Mathematical analysis of the times and positions of the explosions and the times and angles of arrival of the sound waves indicated the average direction and speed of the wind that displaced the sound waves during their trip to the ground. When this wind-vector data is known, the speed of sound in the layer can be computed; from this and from independently known factors such as the molecular weight of the medium, the temperature can then be calculated.

Temperature Results

The temperature results show that in summer as well as in winter the mesopeak occurs at about 50 km. (The mesopeak is the temperature maximum in the mesosphere, where temperatures rise with altitude as a result of strong absorption of solar

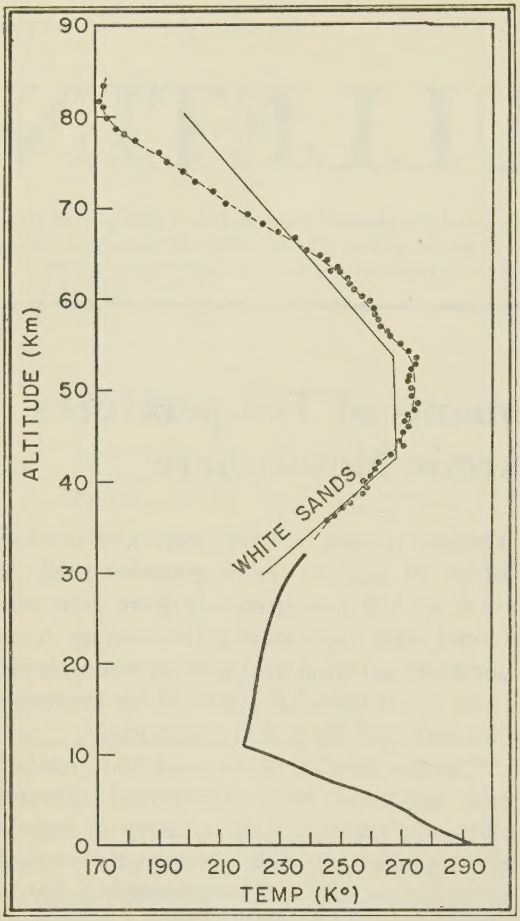

Fig. 1. *Summer Temperature Averages from IGY Rocket-Grenade Experiment at Fort Churchill, Canada. Dots represent running averages from five flights, in July and August 1957; heavy line represents averages from balloon data; and light line shows data from experiments at White Sands, New Mexico, for comparison.*

radiation by the ozone layer, reach a peak, and then fall to the lowest values measured in the atmosphere before beginning a more-or-less continuous rise with increasing height; the mesosphere extends from a height of about 30 km—the top of the stratosphere—to about 82 km.)

In summer (see Fig. 1), there is a nearly linear increase in temperature from about 220° Kelvin at the tropopause (about 11 km) through the stratosphere and lower half of the mesosphere to 275°K at 50 km; in winter (see Fig. 2), however, a slightly negative temperature gradient prevails from 17 to 27 km, with a minimum of about 207°K being reached at the latter height before temperatures again begin to rise. Between 30 km and the mesopeak, temperature gradients are about equal in winter and summer—about 2.5°K per km. However, actual temperatures in this region are about 25° to 30°K higher in summer than in winter. Above the mesopeak, this seasonal difference is reversed.

In winter, there are no pronounced average temperature gradients between the mesopeak and the ceiling of the measurements, at 90 km. In summer, the temperature drops sharply and almost linearly from about 275°K at 53 km to about 170°K at the mesopause (top of mesophere), at 82 km. The difference between the highest measured temperature at 75 km (winter 1957) and the lowest one (summer 1957) at that altitude is 90°K.

A remarkable seasonal variation is evident in both magnitude and altitude distribution of temperatures. The entire summer temperature curve is extremely smooth compared to the scattering that occurs for the region above the mesopeak in winter time. The very stable summer arctic atmosphere between 50 and 90 km thus contrasts with the dynamically very active and unstable medium during December and January. This instability is especially well demonstrated by two pairs of launchings in December 1957 and January 1958. Data from flights on both December 11 and 14, 1957, show a second temperature peak at about 70 km in which the maximum temperature fell from about 290°K on the 11th to about 245°K on the 14th.

The other good example of such an unusual temperature maximum is found in results of the two launchings on January 27, 1958. In both, a sudden temperature rise from approximately 235°K at 75 km to 250°K at 80 km was observed. The second

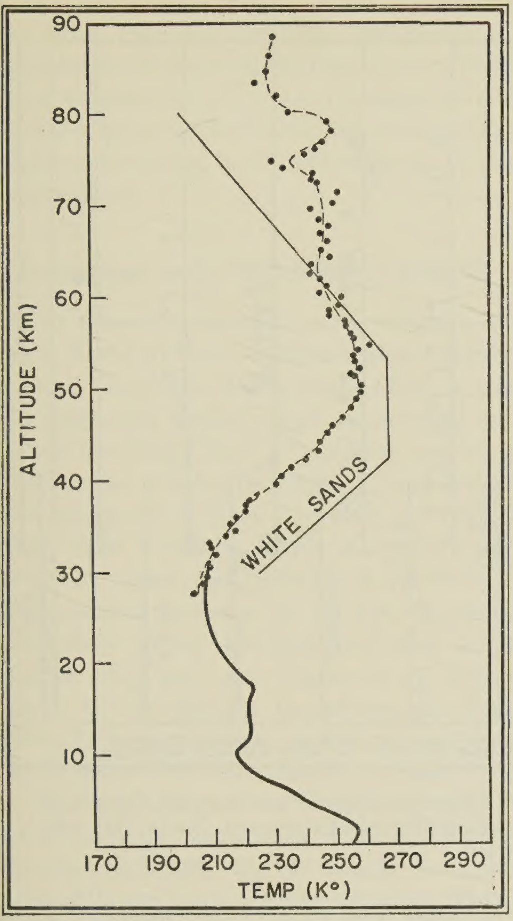

Fig. 2. *Winter Temperature Averages from IGY Rocket-Grenade Experiment at Fort Churchill, Canada. Dots represent running averages from five flights, in November 1956, December 1957, and January 1958; heavy line represents averages from balloon data; and light line shows data from experiments at White Sands, New Mexico, for comparison.*

of these two rockets also carried a falling-sphere experiment as an independent technique for simultaneous atmospheric density measurements. This experiment was successful and the temperature data derived from the density measurements compare well with those from the grenade data. One of these two launchings was conducted at midnight and the other at the following noon in order to observe possible daily variations. With the exception of a possible temperature increase on the order of 5°K from midnight to noon in the 50- to 60-km region, no variations in wind or temperature could be found.

No further daily temperature variations could be deduced from any other winter launchings because, even if they existed, such variations would have been obscured by the much larger ones mentioned above. Below 50 km, where there is less scattering of temperatures, no daily effects could be found.

An analysis of results of the summer launchings also seems to indicate that temperatures at 50 km might be lower by 5° to 10°K during the first half of the day (0000 to 1200) than during the second half (1200 to 2400). However, since only five launchings were made and they were spread over more than one month, these results are not very conclusive. The wind pattern does not show any daily changes at all.

Winds

In contrast to the temperatures, the winds generally show a less unexpected pattern, except during two launchings on January 27, 1958. In general, strong westerly winds prevailed in November and December, and moderate winds from the east were observed in July and August. Wind speeds as high as 165 meters per second from the west were measured in the winter (November 12, 1956), and maximum east winds on the order of 80 m/sec were measured in the summer (August 12, 1957); in general, however, summer wind speeds remained below 50 m/sec. (See Figure 3.)

Wind measurements from both rockets launched on January 27, 1958, were highly unusual and do not seem to fit into the general pattern of strong winds from the west during the winter months. During the last week of January 1958, one of the now-well-known "explosive" stratospheric warmings first observed by R. Sherhag in 1952 spread

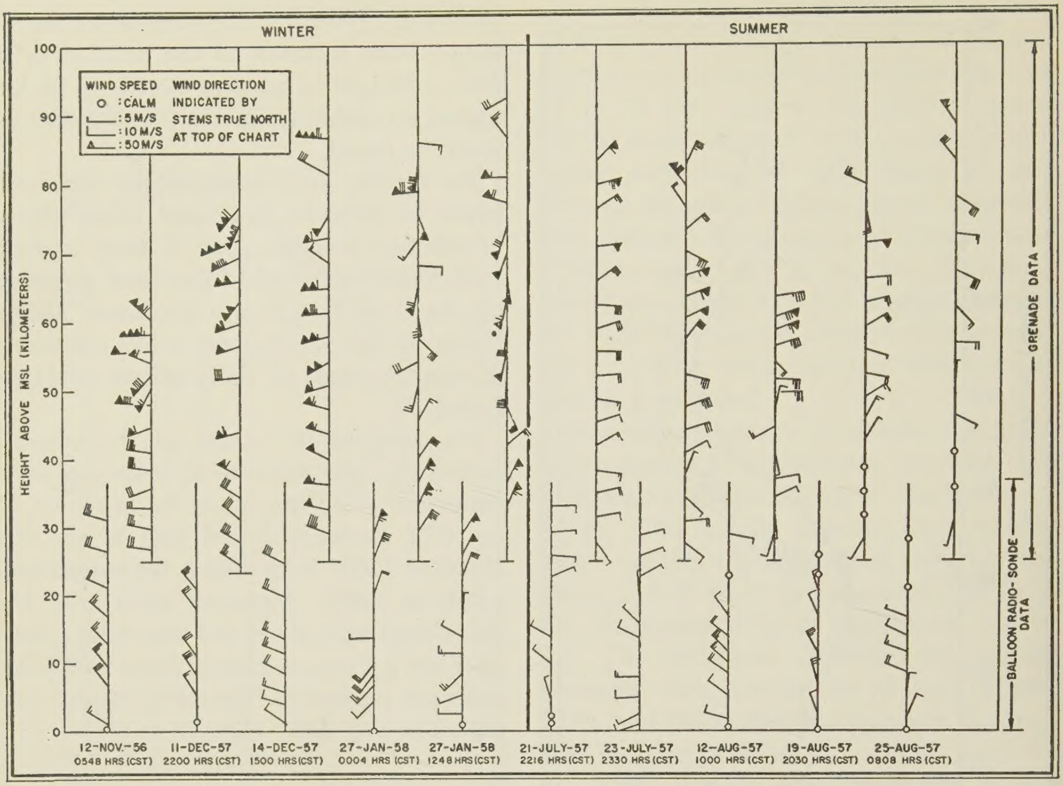

Fig. 3. *Wind Vectors to an Altitude of About 90 Kilometers Above Fort Churchill, Canada, in Winter and Summer, as Obtained in the IGY Rocket-Grenade Experiment. Barbs "fly" with the wind; velocities indicated as shown at upper left.*

westward over northern Canada. (These warmings generally occur between January and March and are believed to indicate a breakdown of the winter-time polar vortex in the stratosphere.)

Although the warming was not yet observed on January 27 at ground level at Fort Churchill, data from the launchings on that day show that breakdown of the winter vortex had in fact taken place at higher altitudes. Winds from the northeast prevailed up to an altitude of 45 km, where the wind direction reversed suddenly and became southerly. The southerlies definitely prevailed up to 75 km, and even above this altitude there was no sign of the usual wintertime westerly circulation.

Temperatures obtained both from balloon soundings over Fort Churchill and from the rocket data for this date were not essentially different from those of the December observations. Two days later, however, rocket measurements of atmospheric density above Fort Churchill by, L. M. Jones, J. W. Peterson, E. J. Schaefer, and H. F. Schulte, indicated an enormous temperature rise in the 30–45 km region but none at lower levels. In another few days (February 3, 1958), some warming was observed at stratospheric levels. Unfortunately, no wind data were obtained for the mesosphere over Fort Churchill after January 27th, but it is generally thought that the polar vortex is not fully restored after such a breakdown. C. E. Palmer points out that on this particular occasion, however, a weak polar vortex was restored in March 1958.

The rocket data clearly demonstrate in this case that the breakdown in stratospheric circulation and the accompanying

warming were preceded by a breakdown of circulation throughout the mesosphere. They also suggest that dynamic processes in the mesosphere are responsible for propagating these phenomena to the lower levels of the atmosphere.

Comparison with White Sands Results

No seasonal temperature variations have been found in the mesosphere above White Sands. The White Sands curve (Figs. 1 and 2) represents somewhat of an average between the Fort Churchill summer and winter curves: the temperatures at and below the mesopeak at Fort Churchill are higher than those at White Sands in summer and lower in winter, and between 50 and 80 km, this pattern reverses. At 80 km, the Fort Churchill winter temperatures are much higher than any ever observed at White Sands at this altitude. In summer, the Fort Churchill temperatures at 80 km are about 30°K below the White Sands average.

The wind pattern at Fort Churchill is qualitatively similar to that at White Sands, although winter winds at Fort Churchill are much stronger than at White Sands. Summer winds at both latitudes are approximately of the same magnitude.

Conclusions

The uniform temperatures measured during July and August 1957 appear to show thermal equilibrium during this period. The investigators conclude, therefore, that temperatures throughout the mesosphere are determined by radiation processes at these latitudes during the summer. For the region above the mesopeak, these arctic summer temperatures are much lower than summer temperatures at middle latitudes. This should make it easier to calculate the concentration and behavior of photochemically active atmospheric constitutents, such as ozone (O_3), at these altitudes. It might be further concluded that the finding that the O_3 concentration shows a very strong latitudinal dependence at lower altitudes also holds true for altitudes all the way up to 90 km. This is especially important since O_3 is believed to be in photochemical equilibrium above 40 km, and any latitudinal variation must therefore be brought about directly by radiation.

The high and unexpectedly irregular temperatures during the winter months, on the other hand, suggest that dynamic processes, specifically subsidence (a descending motion of air, usually over a broad area), are responsible for the thermal state of the mesosphere in the winter. It would be difficult to derive an atmospheric model to explain the results of the winter launchings strictly on a radiative basis. The unusual results of the two January 27th launchings also support this picture of dynamically controlled temperatures.

The very low temperatures observed in summer at 80 km may shed new light on the formation of noctilucent clouds, which are observed predominantly in the northern sky in summer at about this altitude. These temperatures (about 170°K) correspond approximately to the radiation-equilibrium temperature of 166°K cited by E. H. Vestine and D. Deirmendjian for condensation-nuclei near the earth, on the dark side. Vestine and Deirmendjian point out that, at 80 km, sufficient energy is communicated in collisions between atmospheric molecules and the nuclei particles to cause the latter to assume nearly the same temperature as the atmosphere in which they are suspended. At higher altitudes, radiation may be the dominant factor and the particles would no longer have the same temperature as the surrounding air.

Thus, at 80 km, the condensation nuclei and surrounding atmospheric gas are at the same low temperature; at higher altitudes these temperatures differ because of radiation, and at lower altitudes the temperatures are too high to support condensation. The 170°K temperature detected at

this height in the rocket experiment is sufficiently low to cause condensation on these nuclei of even the small amounts of water vapor present.

It is further concluded from the measurements at Fort Churchill and White Sands that the circulation from about 80 km down follows very closely the circumpolar pattern found to exist at lower altitudes in the stratosphere. Although this pattern does not reflect the characteristic day-to-day variation of meteorological elements in the troposphere, it is affected by large-scale seasonal events such as the reversal in circulation from summer to winter, and vice versa, for which the results of the flights on January 27, 1958 serve as an especially good example.

The fact that such seasonal events can be observed to altitudes nearly up to the base of the ionosphere (about 82 km) suggests very strongly that large-scale meteorological events are not limited to either the troposphere or the stratosphere, or to both, but also involve higher atmospheric levels. Moreover, the chronological sequence of the spreading of abnormally high temperatures through the atmosphere shows that these events occur first at higher altitudes, and then penetrate downward toward the troposphere over a period of several days or weeks. Thus, these meteorological effects may be governed by events at altitudes above the range of this experiment, with the mesosphere serving only as a dynamic link in propagating them downward.

The view that the breakdown in circulation observed on January 27, 1958 is not caused by the absorption of extraterrestrial radiation in the region below 80 km is supported by the results of a study by L. R. Davis, O. E. Berg, and L. H. Meredith. Their measurements of auroral-particle radiation, during a rocket flight at Fort Churchill on January 25, 1958, show no such radiation below 90 km. On the other hand, very strong correlations have recently been observed by L. G. Jacchia between solar events and atmospheric density at an altitude of 300 km. (See *Bulletin No. 32*).

It is planned to continue these simultaneous measurements of temperatures and winds up to the highest possible altitudes in future rocket measurements. Day-to-day synoptic measurements such as those carried out on a world-wide basis by radiosonde balloons are not believed necessary for the higher-altitude investigations. However, a set of "semi-synoptic" rocket flights at strategic locations (equatorial regions, middle latitudes, and several sites near and within the polar regions) will make possible a thorough insight into the relations between the upper atmosphere and the troposphere.

Unusual Solar-Terrestrial Event

The following report is based on material prepared by the National Bureau of Standards, relating to observations at its Boulder Laboratories by the solar research group of the Radio Warning Services Section.

An unusual solar event, completely at variance with the experience of many years, occurred on June 9, 1959, and has raised questions about the validity of what were considered established relationships between these events and terrestrial effects such as radio fadeouts and geomagnetic disturbances. (For a discussion of the terrestrial effects of flares and other solar activity, see *Bulletin No. 32*.)

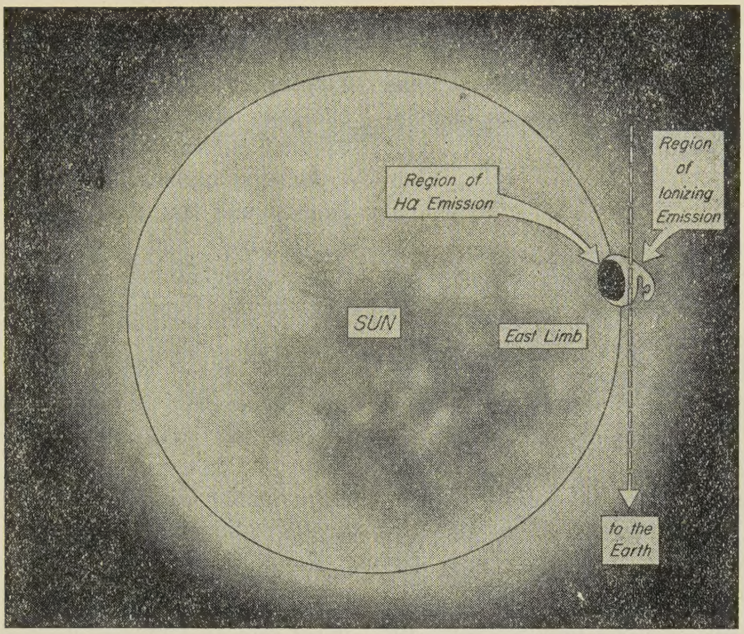

Fig. 4. *Cross-section of Sun, From Above, During the Unusual Solar Event of June 9, 1959.*

The investigation of the association between solar events, ionospheric disturbances, and geomagnetic storms has played an important part in the Bureau's radio propagation prediction services, particularly in the radio disturbance warning network. Part of this prediction work, based on the analysis and evaluation of solar radio data received from many sources, involves determination of the relationships between various solar events, radio fadeout, and temporary changes in the earth's magnetic field. The unusual solar event of June 9 does not fit the previous understanding of such associations, and is therefore considered an anomaly of major importance.

Description of Event

A severe radio blackout of very long duration, accompanied by large radio-noise outbursts on a number of wavelengths began at 1630 UT on June 9, 1959. No solar flare could be seen on the sun's disk, however, although a prominent flare would normally be visible at the same time as this type of radio disturbance is recorded.

As soon as the severity of the blackout became apparent, radio and optical observations were intensified. The initial position of the radio-burst source on the sun's disk was established, by high-resolution scan at a wave length of 10.7 centimeters (about 3000 megacycles), to be N 24, E 90, on the eastern edge of the disk. In the light of the hydrogen-alpha (Hα) spectral line, only jets (spikes emerging from the chromosphere) and bright loops (a rare type of gaseous prominence generated by large and active sunspot groups) were observed at this position. It was not until almost 1½ hours after the first event that the expected Hα flare became observable, at N 19, E 90. (See Figure 4.)

Complete blackout of the Bureau's radio station, WWV, occurred at a number of receiving locations. Cosmic-noise absorption of an outstanding nature (3 +) was evidenced by the great drop-off in received signal strength, and also by the unusually slow onset of the absorption. Solar radio bursts at relatively low frequencies (18 mc) were

classified as 3+ in importance, and bursts at high frequencies (about 3000 and 70,000 mc) were very strong. These observations classify the ionospheric events as of relatively great importance (3+).

Discussion

Past observations of such outstanding events have, in almost all cases, revealed the presence of an Hα flare of major importance. The absence of such a flare in itself established the June 9 event as a most unusual one. The anomaly also creates a number of problems concerning the understanding of solar-terrestrial relationship.

Both of the Hα jet ejections on this occasion appeared to be based near the sun's eastern limb on the side facing away from the earth. The jet phenomenon, together with the unusually late appearance of the flare itself, lead to the speculation that an early stage of the flare also occurred on the other side of the sun and in closer time-association with the earlier terrestrial events.

There is, of course, no way of establishing the actual occurrence of this unobserved flare on the other side of the sun as a fact. The assumption that there was such a flare presents still another problem: ascertaining how the solar radio emission and the ionizing emission that produced the radio fadeout could have reached the earth if they were generated in the same solar region as the unobserved Hα flare. Normally, both emissions—Hα and the ionizing radiation—travel in essentially straight lines. For these emissions to come from the same source, it would be necessary to assume a different trajectory for the Hα emission from the other side of the sun than for the ionizing radiation, a conclusion at variance with many prior observations. However, it may be inferred that the Hα flare originated at a lower level in the sun's atmosphere than the source of the emissions. This inference would help to explain why the Hα flare was not observed, although the ionizing radiation was able to reach the earth.

Another unusual feature of the event of June 9 was the exceptionally low velocity of the radio-emission source, as deduced from observations at two separate low frequencies. Slow-drift bursts on dynamic spectrum records (see *Bulletin No. 29*) normally show velocities of the order of 1000 kilometers per second at metric wave lengths. By comparison, velocities derived from 18-, 38-, and 200-mc fixed-frequency observations during the June 9 event average about 250 km/sec.

An additional unusual aspect of the event was the lack of subsequent major geomagnetic and ionospheric storms. The earth's magnetic field registered no major disturbances in the following few days, although there was a "sudden commencement" (the sudden onset of a magnetic disturbance) on June 11, followed by moderately disturbed three-hour K figures of 5, 6, and 5. Under ordinary circumstances, major disturbances would be expected. (The K-index expresses geomagnetic activity in terms of a scale ranging from 0, or very quiet, to 9, or extremely disturbed.)

Conclusions

The lack of geomagnetic and ionospheric disturbances in the solar event of June 9, coupled with the other apparent anomalies, has forced a critical reappraisal of past techniques of observation and of earlier conclusions from observational data. The resulting inquiry can be expected to lead to increased understanding of the relationships between the individual components of associated solar events and to a consequent improvement in radio-propagation prediction methods.

Nighttime Radio Propagation in Equatorial Regions

First Results of the IGY Amateur Radio Research Program

The following report is based on a more detailed account by Mason P. Southworth, project supervisor of the American Radio Relay League's IGY Propagation Research Project. The earlier report appeared in the Journal of Geophysical Research, *February 1960.*

During the IGY, thousands of reports by radio amateurs ("hams") of ionospheric propagation at frequencies of 50–54 megacycles per second and 144–148 mc/sec were collected by the ARRL, evaluated, and transcribed to punched cards for computer reduction and subsequent analysis. (*Bulletin No. 15* outlines the aims and organization of the Propagation Research Project and describes briefly the propagation "modes" investigated.)

In 1947, radio amateurs made the first 50-mc/sec contacts across the magnetic equator—between Mexico and Argentina. Since then, many similar very-high-frequency (VHF) contacts have shown that such "transequatorial-scatter" propagation can consistently be achieved during evening hours throughout sunspot maximum, when special conditions prevail in the equatorial ionosphere; it has also been shown that such transmissions fall off greatly, or cannot be effected at all, during the portion of the 11-year solar cycle when sunspot activity is at a minimum. (Radio signals at frequencies higher than about 30 mc/sec normally penetrate the ionosphere entirely and continue into space; under special conditions, however, generally by "scatter" from irregularities or discontinuities in ionization density, or by reflection from clouds or patches of unusually high ionization in the E-region—termed sporadic E—VHF signals up to about 100 mc/sec can be reflected back to earth.)

The ARRL-IGY Propagation Research Project was made possible by the hundreds of radio amateurs who contributed long hours of listening for 50-mc/sec signals. A large number of participants, in addition to spending many evenings at their sets waiting for transequatorial propagation to begin, remained late into the night in order to catch the very end. Moreover, several stations cooperated by transmitting continuous beacon signals. Negative reports—dates and times when 50-mc/sec transmissions were not received—were also made in order to give as complete a picture as possible of the record of transequatorial propagation.

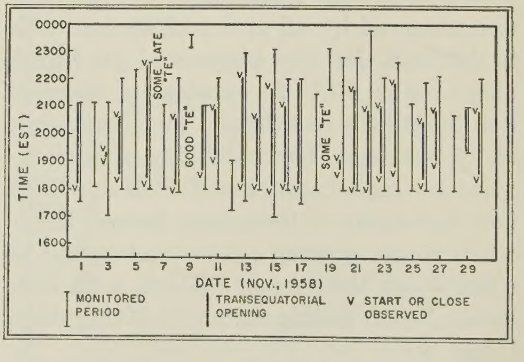

Fig. 5. *Monitoring Record for Amateur Station PZ1AE, Paramaribo, Surinam, November 1958. "TE" refers to transequatorial propagation.*

Typical of the PRP participants was amateur operator PZ1AE, of Paramaribo, Surinam. Figure 5 is a monitoring record

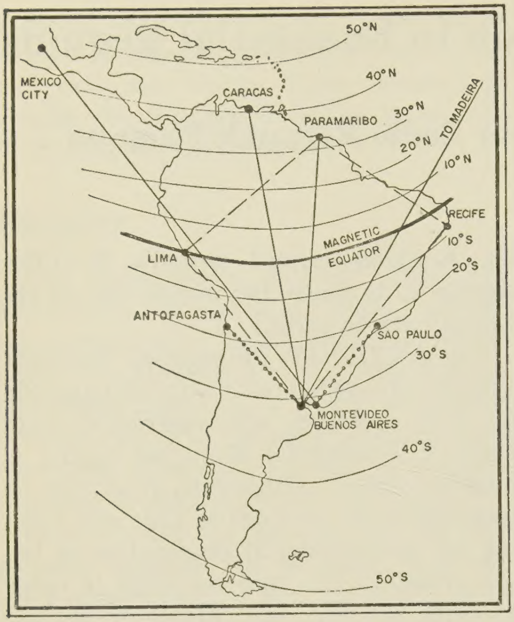

Fig. 6. *Typical Paths of 50-mc/sec Night-time Signals Observed by Radio Amateurs in South America. Solid lines are long-range, dashed lines medium-range, and small circles short-range paths.*

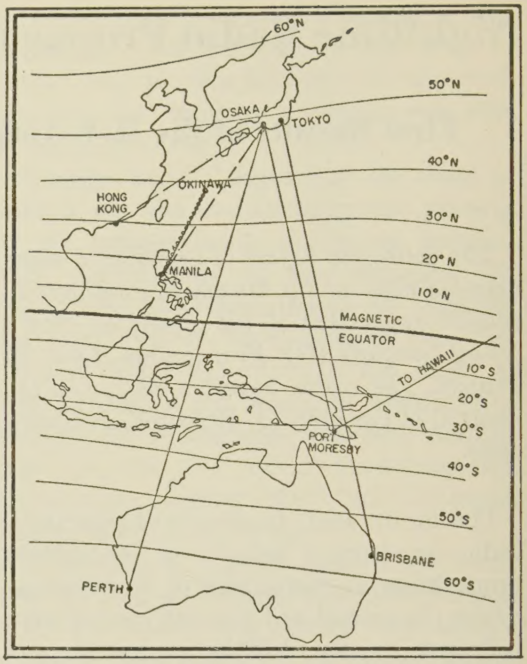

Fig. 7. *Typical Paths of 50-mc/sec Night-time Signals Observed by Radio Amateurs in the Far East. Paths as in Figure 6.*

for operator PZ1AE during November 1958. In this interval, PZ1AE reported all but three of the total number of instances of South American transequatorial propagation observed by all of the 17 stations able to detect it. He also pinpointed the beginning time on 20 of 21 evenings of observation during the month, and the ending time on 17 evenings. The reliability of such reports by radio amateurs derives from the fact that many of them have trained themselves to use existing commercial signals as beacons—in the case of PZ1AE, a 24-hour trolley-repair paging station in Montevideo, Uruguay.

Equatorial Propagation Paths

For convenience, the nocturnal 50-mc/sec propagation reported from South America, and more recently from the Far East, has been separated into three main categories on the basis of path length (see Figs. 6 and 7). The longest are the transequatorial paths, ranging from 4000 to nearly 9000 kilometers in length. These paths are roughly bisected by the magnetic equator and their end points generally have magnetic dip angles between 20° and 60°. Medium-range paths are from 2500 to 4000 km in length and paths between 200 and 2500 km long are in the short-range category.

Over long-range transequatorial paths, amateurs in the Buenos Aires-Montevideo area can contact Paramaribo, Caracas, and Mexico City (Fig. 6) almost nightly during the equinoctial months of each year. The Madeira Islands are heard only slightly less often. Stations in Paramaribo and the Buenos Aires-Montevideo region also receive medium-range signals from Lima and Recife, usually at the same time they are receiving long-range signals from each other and from other stations. Typical short-range paths are those linking Buenos Aires-Montevideo with Sao Paulo and An-

tofagasta. The distances traversed by these short-range paths resemble those of single-hop equatorial sporadic-E propagation (see *Bulletin Nos. 25, 29, and 33*); however, the short-range 50-mc/sec signals described in the present report are heard at the same times and with the same regularity as the longer-range transequatorial signals.

During the past few years, additional 50-mc/sec transequatorial data have also been obtained in other parts of the world. Australian amateurs first heard evening 50-mc/sec propagation from Japan in early 1957, and in the same year regular work was begun between southern Europe and southern Africa. Figure 7 shows typical Far Eastern paths for this mode of propagation. Observations by the National Bureau of Standards over the Phillipines-Okinawa circuit (see *Bulletin No. 26*) show the exact short-range characteristics that would be expected on the basis of the South American amateur results.

Daily Variations

The top five curves of Figure 8 show the daily characteristics in October 1958 of propagation over specific 50-mc/sec transequatorial circuits in the Western Hemisphere. The bottom curve shows the same thing for 40-mc/sec long-range echoes heard by B. Dueño at the University of Puerto Rico. The curves show the number of evenings that signals were received on each path in terms of local time at the mid-point of the path.

The 50-mc/sec curves show similar maxima at 2100–2200 hours, in good agreement with the mid-point time peak of 2130 hours reported by R. G. Cracknell for 50-mc/sec transmission between Southern Rhodesia and Cyprus. Results for the 40-mc/sec transequatorial echoes are markedly different, however. The 40-mc/sec signals faded out at Puerto Rico before the 50-mc/sec transmissions of Buenos Aires amateurs began to reach Puerto Rico. If the same mechanism accounts for both modes, it must be a very unusual one, especially since the 40-mc/sec echoes do not reappear later in the evening.

Data on 50-mc/sec transequatorial propagation in other parts of the world have been plotted in the same manner as the South American data. In these plots, a circuit from Argentina to Hawaii is the only one with a daily variation distinctly resembling that of the 40-mc/sec path described above. They may share causative mechanisms as well. A curve for an Australia to Hawaii path appears to represent standard 50-mc/sec transequatorial propagation. Curves for paths from Japan to various parts of Australia have two parts, representing flutter fading and steady signals. While flutter fading is almost always present in South American transequatorial

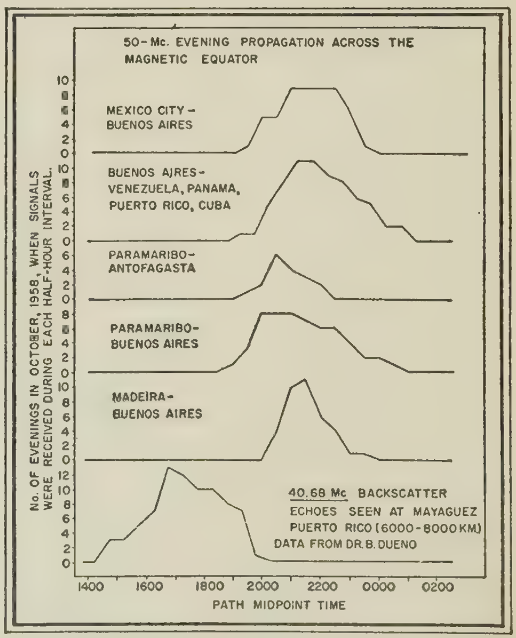

Fig. 8. *Daily Variations in Time of Occurrence of 50-mc/sec Transequatorial Propagation for Various Paths in and to South America, in October 1958. Curves for other parts of the world and for medium- and short-range equatorial propagation are essentially similar. A 40-mc/sec path is shown at the bottom for comparison.*

propagation, the Japanese and Australian paths have steady signals as well. The steady signals tend to appear first and may resemble the Puerto Rico backscatter signals. The fluttering signals seem similar in behavior to those over other transequatorial paths.

Daily variations over several medium-range paths, five circuits across South America and a sixth from Japan to Manila, have been similarly plotted. All of these circuits show about the same 2100- to 2200-hour maximum as the transequatorial paths. So does the curve drawn from Dueño's 40-mc/sec medium-range backscatter results, unlike the 40-mc/sec curve for long-range paths.

Daily plots of short-range propagation were drawn for a Buenos Aires-to-Antofagasta path during October 1957 and October 1958. These were compared with a plot for the anomalous path between Okinawa and the Phillipines (see *Bulletin No. 26*). Although the ordinate scale for the anomalous Okinawa-Philippines mode is in terms of signal strength rather than frequency of occurrence, there is a strong similarity between the curves. In addition, the optimum and closing times for the Okinawa-Philippines transmissions are practically identical to those of the transequatorial and medium-range propagation.

The relationship, as described above, between the short-range modes (which appear much like sporadic E) and the longer-range modes may seem improbable. However, the long-range transequatorial, the medium-range, and the short-range signals were all found to begin, reach maxima, and end at almost the same mid-point times. Moreover, all of them, more often than not, have similar fading characteristics and all are observed on the same evenings.

Because of the times of day these modes are operative, they seem less likely to involve ionospheric layer tilts than do transequatorial echoes heard at the Virgin Islands and Puerto Rico on lower frequencies. The 50-mc/sec amateur observations appear more closely connected in time with a patch of high electron density recently observed by D. M. Gates, of NBS, over Bogotá (magnetic dip angle 32°) at about 2200 hours. This patch, with a critical frequency of about 21 mc/sec, can account for a few circuits directly. If it were known whether such patches have also formed in the Far East and in South America south of the equator, as well as when and where they may have formed, some additional paths might perhaps be explained.

Seasonal Variations

In order to observe the variation patterns of equatorial modes throughout the year, plots of the number of nights per month on which transequatorial signals were received were made for the Americas and the Far East for the period January 1957 through July 1959 (see Fig. 9). Seasonal graphs for

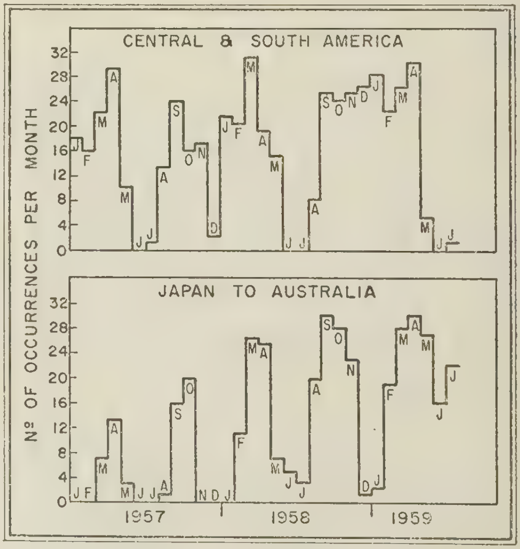

Fig. 9. *Seasonal Variations in the Frequency of Occurrence of Evening Transequatorial Propagation at 50 mc/sec.*

medium- and short-range propagation look much the same. (For about the first nine months of 1957, Australian amateurs were

not able to use the 50-mc/sec band. Hence, there were fewer transequatorial contacts than would otherwise have been made, and the curve representing this interval cannot, therefore, be accepted at face value.)

Past references to transequatorial propagation have mentioned maxima at the equinoxes and minima at the solstices. In the present data, however, it appears that the situation is not quite so simple. While the equinoctial months of March-April and September-October often have maxima, the solstice periods of December-January 1958 and 1959, in South America, have even higher maxima, and June and July 1959 in the Far East were not far below the equinox peak.

A critical look back over the data for the solstices shows that the November-through-February period is almost always higher in activity than May through August in the Americas, whereas the opposite is true for Australia-Japan paths. An obvious geophysical factor with which this difference between the Western Hemisphere and the Far East may be related is the change in relative position of the magnetic equator with change in longitude. On this side of the world the magnetic equator is south of the geographic equator, while in the Far East their positions are reversed (see *Bulletin No. 17*, Fig. 1). Perhaps the solstice when transequatorial scatter is likely to be high is the one that occurs when it is summer along the magnetic equator. H. W. Wells has reported the same relationship with respect to the equatorial spread-F mode of propagation during the period 1938–1954. Dueño's 40-mc/sec data for 1958 and 1959, on the other hand, do not reveal a solstitial preference.

Relationship to Geomagnetic Activity

Western Hemisphere transequatorial propagation at 50 mc/sec is compared with magnetic activity in Figure 10. The figure shows the interval during each evening

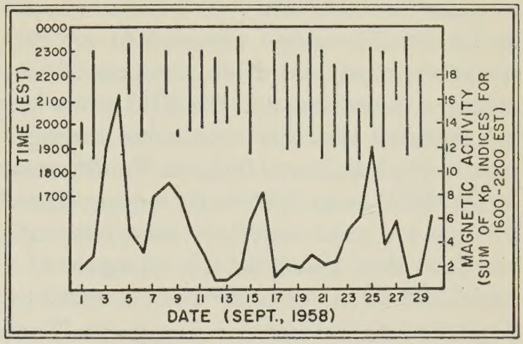

Fig. 10. *Comparison Between Times of Occurrence of Transequatorial Propagation and Geomagnetic Activity during September 1958.* K_p *indices express intensity of geomagnetic activity on a scale ranging from O (very quiet) to 9 (extremely disturbed); in the graph above, two* K_p *indices have been summed to obtain a figure for the hours 1600–2200 EST on each evening.*

(roughly in terms of average path midpoint time) when such propagation was observed somewhere in South America. The curve thus produced is compared with magnetic activity during the hours of 1600–2200 EST for each evening. September is one of the best months for transequatorial propagation; yet, almost everytime there was high magnetic activity, such propagation was either nonexistent or did not begin until the usual optimum hour was reached. When conditions were less favorable for transequatorial transmission, a very mild magnetic disturbance sufficed to eliminate the evening's 50-mc/sec contacts. Such an inverse correlation with magnetic activity is a well-known characteristic of equatorial spread-F propagation. However, long-range evening echoes at 40 mc/sec from Puerto Rico do not show this relationship.

Frequency and Fading Characteristics

The upper frequency limit of these equatorial modes is much above 50 mc/sec. Police signals from Cyprus at 70 to 72 mc/sec, for example, are received in the Rhodesias just about as often as are 50-mc/sec

amateur transmissions. Television signals as high as 72 mc/sec (channel 4) are frequently propagated from Caracas, Venezuela, to Argentina, and the NBS group has extrapolated that the anomalous propagation in the Far East (*Bulletin No. 26*) may be identifiable up to 80 or 90 mc/sec. These findings are quite consistent, moreover, with the fact that Brazilian TV channels 3, 4 and 5 (60–82 mc/sec) are often received by Argentine stations over similar paths. Thus, future investigations of these phenomena should probably be conducted in terms of frequencies above 50 mc/sec rather than the traditional lower ones.

Most long-range transequatorial signals, and very often those of medium and short range, have a characteristic rapid flutter fading, which seems to be on the order of 5 cycles per second. This fading is usually very deep and capable of modulating a strong signal completely into the noise level. Little more is known about this phenomenon as yet, but an amateur recording program has been set up that should yield records suitable for more detailed analysis.

Conclusions

Transequatorial scatter propagation of radio signals, as observed by amateurs at 50–75 mc/sec, is intimately connected with medium-range propagation to the neighborhood of the magnetic equator and also with short-range transmission for distances beyond a few hundred kilometers. All of these categories occur most frequently at path mid-point times of 2100–2200 hours, are most pronounced around the equinoxes, and have similar fading characteristics.

These 50-mc/sec echoes are probably not related to the long-range echoes heard on lower frequencies at the Virgin Islands and Puerto Rico, where ionospheric layer tilts are believed to be the cause. Although the amateur 50-mc/sec results do show a daily variation similar to that of the 40-mc/sec medium-range echoes at Puerto Rico, the amateur equipments are considerably more sensitive than the Puerto Rico backscatter sounder, and different mechanisms may therefore still be involved. One such mechanism might be the patch of high electron density that has appeared at 2200 hours in the true-height profiles constructed for the NBS chain of stations along the 75°W meridian (see *Bulletin No. 29*). The transequatorial scatter observed at 50 mc/sec also has some of the same general characteristics (daily and seasonal variation and relation to geomagnetic activity) as equatorial spread F.

International Rocket Intervals

In order to obtain solar, geophysical, and meteorological data simultaneously in a number of widely separated regions of the world, the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU) is sponsoring a series of International Rocket Intervals.

The first rocket interval took place November 16–22, 1959, and was part of the IGC-59 program, successor to the IGY. The second interval, September 16–22, 1960, was designated by COSPAR to coincide with part of the World Meteorological Interval (WMI) planned for this period in accordance with the International Geophysical Calendar 1960 (see *Bulletin No. 30*). (WMI are characterized by a general, world-wide intensification of meteorological, solar, and

geophysical observations.) The Space Science Board (SSB) of the National Academy of Sciences coordinated US participation in the first two International Rocket Intervals.

COSPAR has scheduled two major International Rocket Intervals for 1961. The first, from February 12 to 18, will be concerned primarily with solar-terrestrial effects related to the total solar eclipse expected on February 15, and with winter atmospheric structure in the Northern Hemisphere. Launchings during the second major interval of 1961, July 16–25, will emphasize atmospheric structure during the Northern Hemisphere summer. Rocket flights designed for solar and upper-atmosphere observations will also be made during the seasonal meteorological rocket intervals (see below) scheduled for January, April, and October 1961.

September 1960 Rocket Interval: Approximately 27 research rockets were launched as part of the US contribution to the September 16–22 interval, 22 of them for meteorological measurements and the remainder for other geophysical investigations. Scheduled for geophysical flights were a National Aeronautics and Space Administration experiment using nuclear emulsions to investigate the lower portions of the Van Allen radiation region; Air Force Geophysics Research Directorate experiments dealing with atmospheric composition and density; and Army Ballistic Research Laboratories rocket and balloon flights carrying water-vapor experiments and frost-point hygrometers. Results of these experiments, as well as of the meteorological flights, will be reported by the SSB to COSPAR for distribution to the world scientific community, and will also be deposited in the IGY World Data Centers.

Meteorological Flights: For more than 20 years, weather balloons launched two or more times daily from an increasingly dense network of stations throughout the world have provided data on pressure, temperature, humidity, and winds up to an altitude of about 100,000 feet (about 20 miles). The development of small, relatively inexpensive scientific rockets during the past few years now makes it possible to extend this synoptic weather-balloon technique to altitudes two or more times as great through simultaneous launchings from a number of widely separated points.

During the September 1960 interval, temperatures and air densities were measured each day by Arcas and Loki rockets launched from sites in Florida, California, Nevada, Virginia, and New Mexico. These meteorological sounding rockets covered an altitude range of 75,000 to 200,000 feet (about 15–40 miles); however, one Arcas rocket reached an altitude of 264,500 feet above White Sands, New Mexico, the greatest height ever achieved by this type of rocket.

The sites of these launchings constitute a meteorological rocket network established to gather synoptic meteorological data on a nationwide basis for month-long periods in the winter, spring, summer, and autumn. The flights made by this network are part of the US contribution to the International Rocket Intervals.

NASA Nuclear Emulsion Experiment: The NASA Nuclear Emulsion Recovery Vehicle ("NERV") was designed to measure radiation in the Van Allen region (see *Bulletin No. 30*) and return the recorded data to earth for study. The four-stage, solid-propellant Argo D-8 rocket, was launched southwestward from Point Arguello, California, on September 19, 1960. It sent an 83-pound payload to an altitude of about 1200 miles and for a distance of approximately 1200 miles down range, as planned. The payload was parachuted to the sea surface and recovered by US Navy vessels stationed in the impact area.

The stack of nuclear emulsions carried by the vehicle was designed to record the passage of all charged particles with energies of 5,000,000 electron volts or greater, thus providing a profile through the geo-

magnetically trapped radiation in this geographic region. The emulsions were exposed to radiation from an altitude of about 300 statute miles on the up leg of the flight, through apogee, and down to a height of about 600 miles.

In this geographic area, the innermost of the two Van Allen belts of high-intensity radiation within the vast atmospheric region of geomagnetic trapping dips to within approximately 700 miles of the Earth's surface. Hence, the radiation profile includes a substantial portion of this inner high-intensity belt. The NERV flight also carried a related biological experiment using mold spores, and a micrometeorite experiment.

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